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Yoshida

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(54) **SOLID-STATE IMAGING DEVICE**

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See application file for complete search history.

(71) Applicant: **CANON KABUSHIKI KAISHA**,
Tokyo (JP)

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(72) Inventor: **Daisuke Yoshida**, Ebina (JP)

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(73) Assignee: **Canon Kabushiki Kaisha**, Tokyo (JP)

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Primary Examiner — Georgia Y Epps

Assistant Examiner — Kevin Wyatt

(74) *Attorney, Agent, or Firm* — Fitzpatrick, Cella, Harper & Scinto

(51) **Int. Cl.**

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(58) **Field of Classification Search**

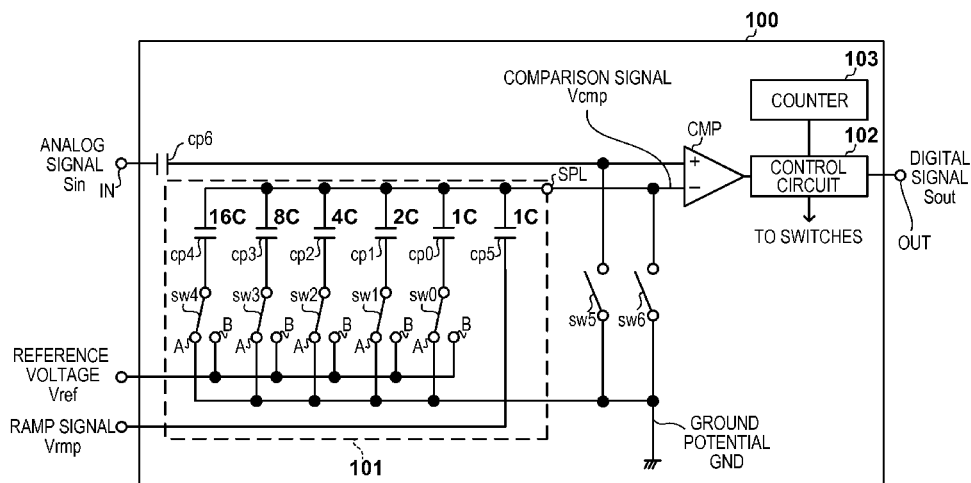
CPC H03M 1/34; H03M 1/44; H03M 1/442; H03M 1/446; H03M 1/1225; H04N 5/3355; H04N 5/378

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ABSTRACT

A solid-state imaging device including an AD converter and a pixel array is provided. The AD converter performs a ramp comparison and a successive-approximation. The AD converter determines a digital value by performing one of the ramp comparison and the successive-approximation as a former comparison operation and then performing the other as a latter comparison operation in the range narrowed down by the former comparison operation. The pixel array supplies, to the AD converter, a reference signal corresponding to a reset level of the pixel, and an image signal having image information. The AD converter performs the latter comparison operation without performing the former comparison operation, when the reference signal is supplied.

15 Claims, 10 Drawing Sheets



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FIG. 1

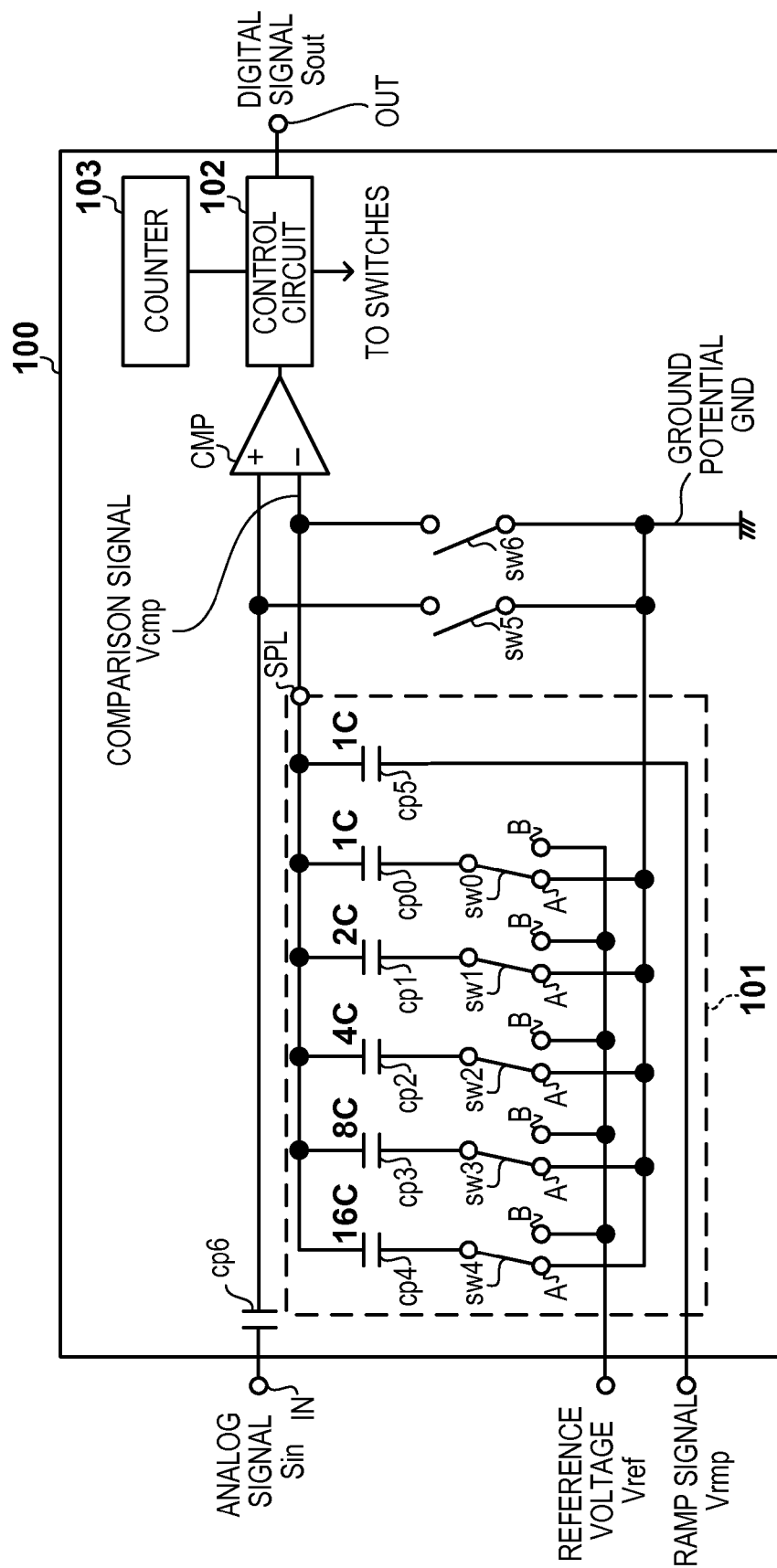


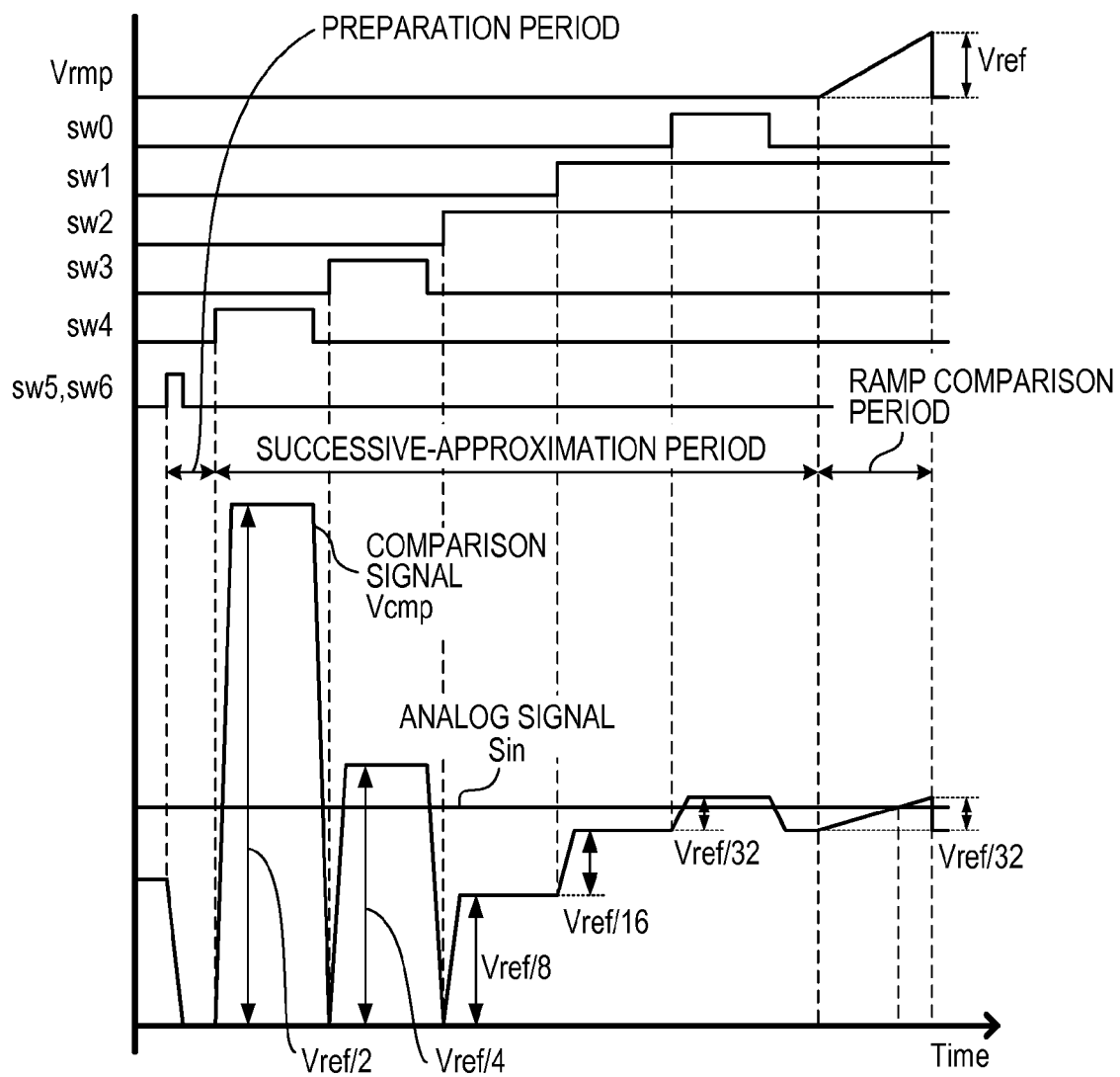
FIG. 2

FIG. 3

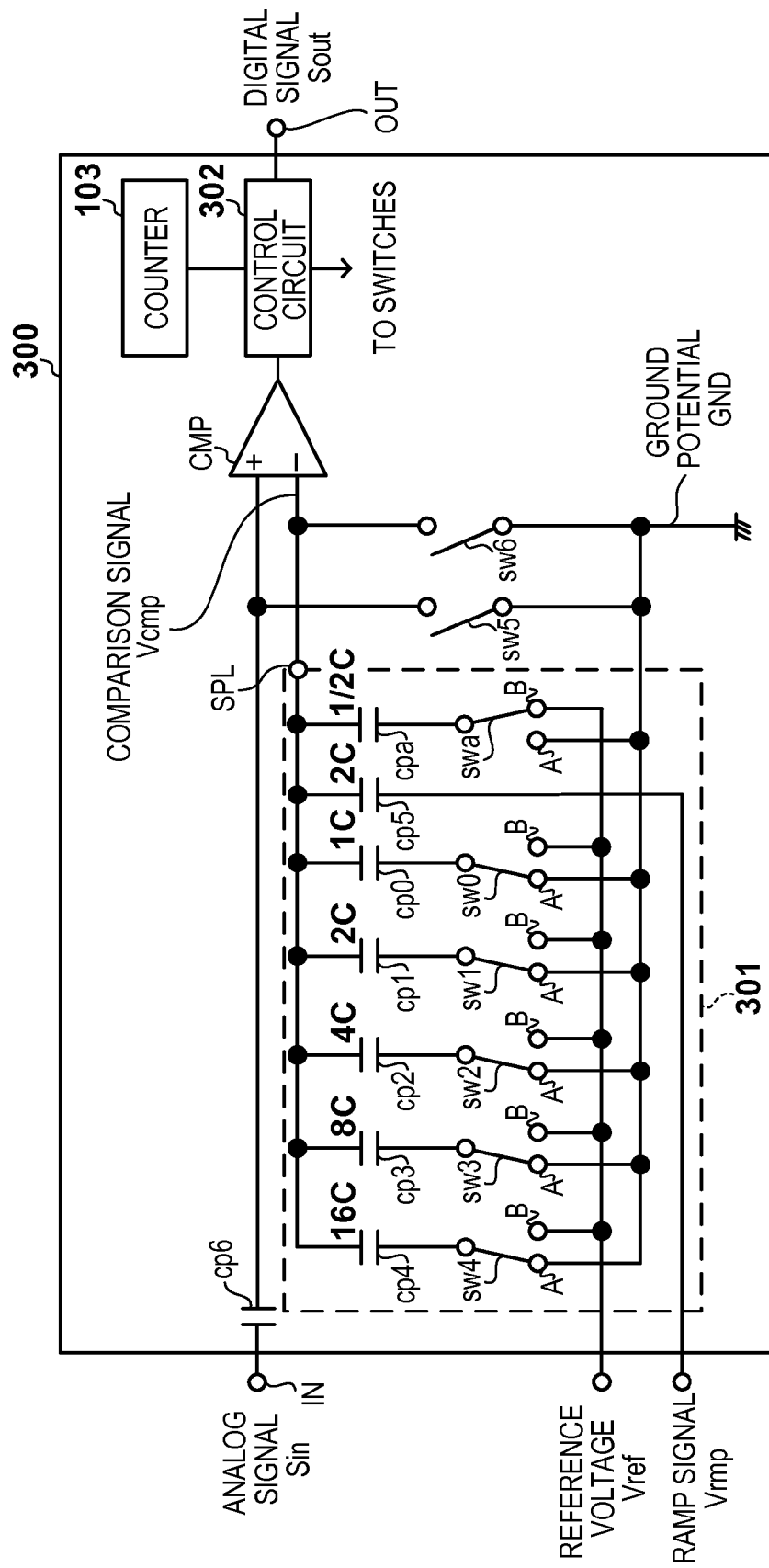


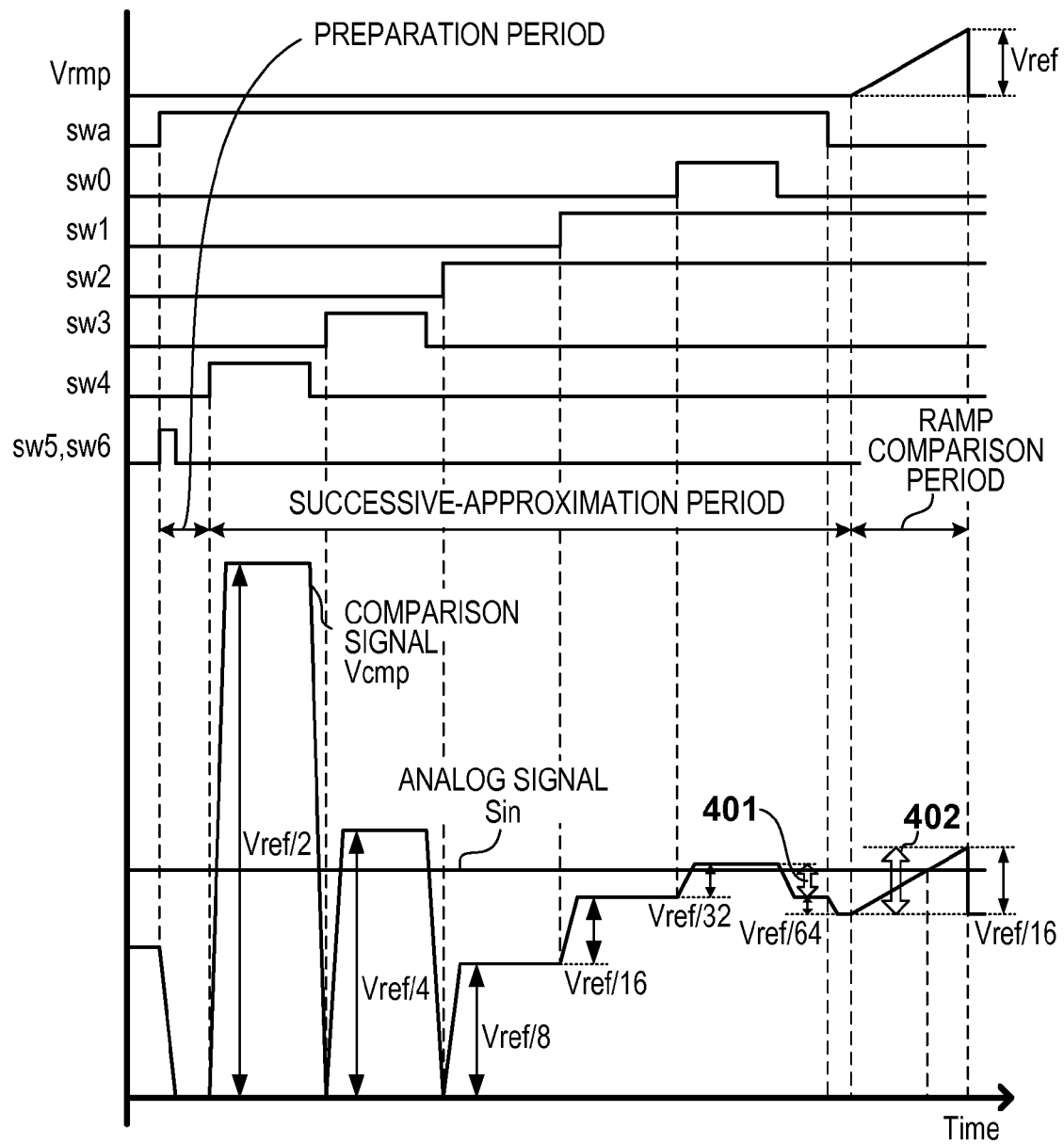
FIG. 4

FIG. 5

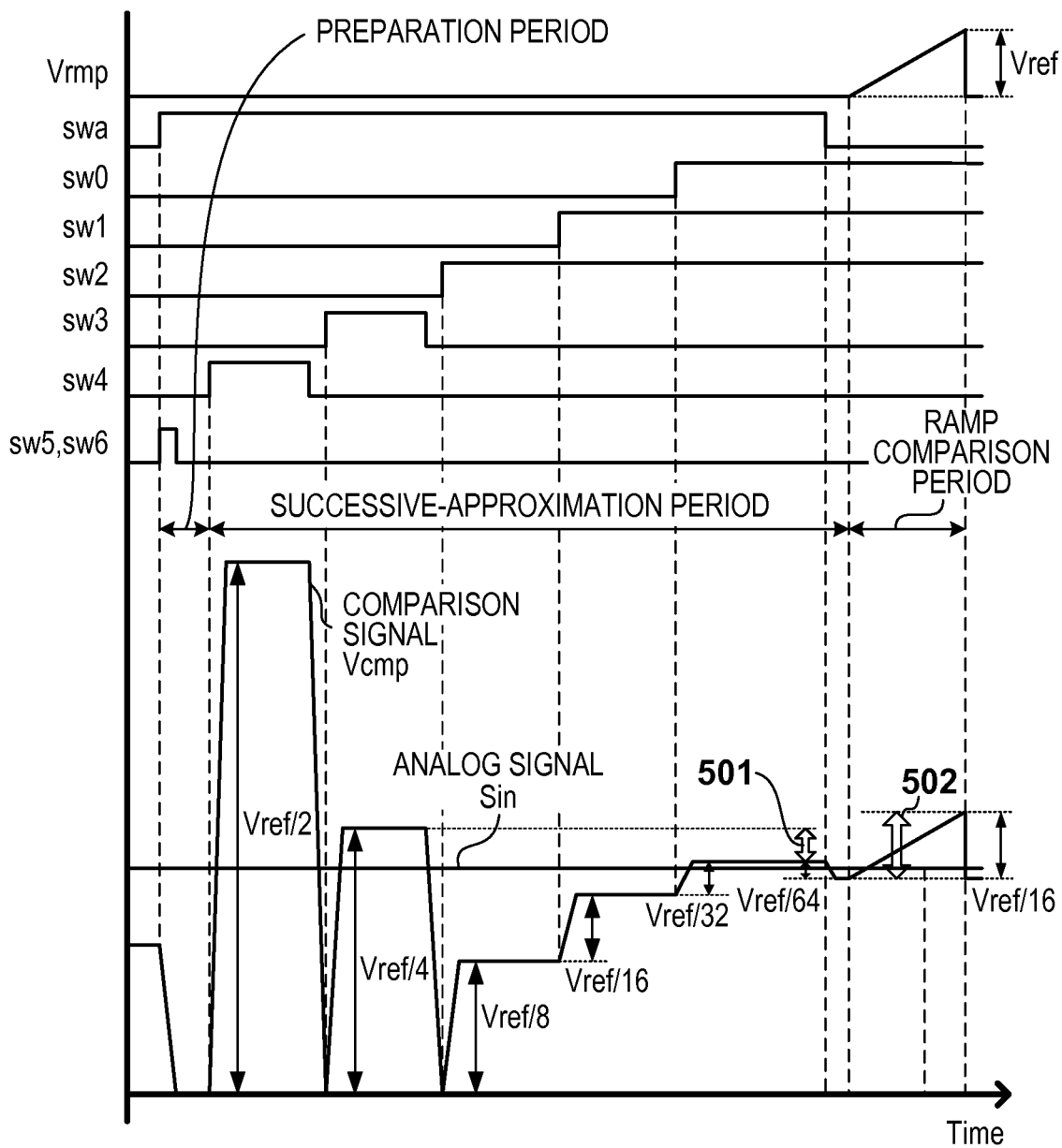


FIG. 6

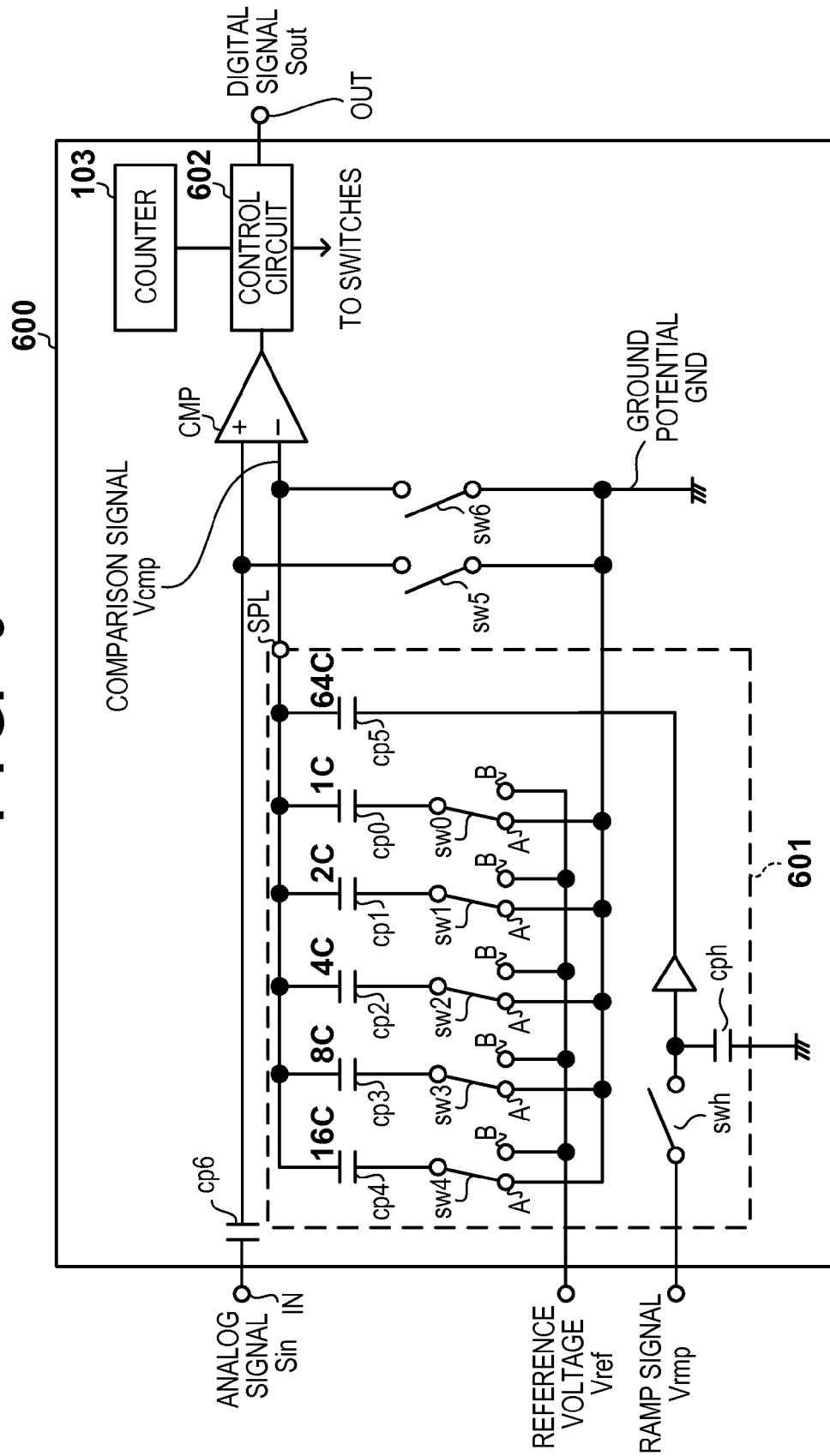


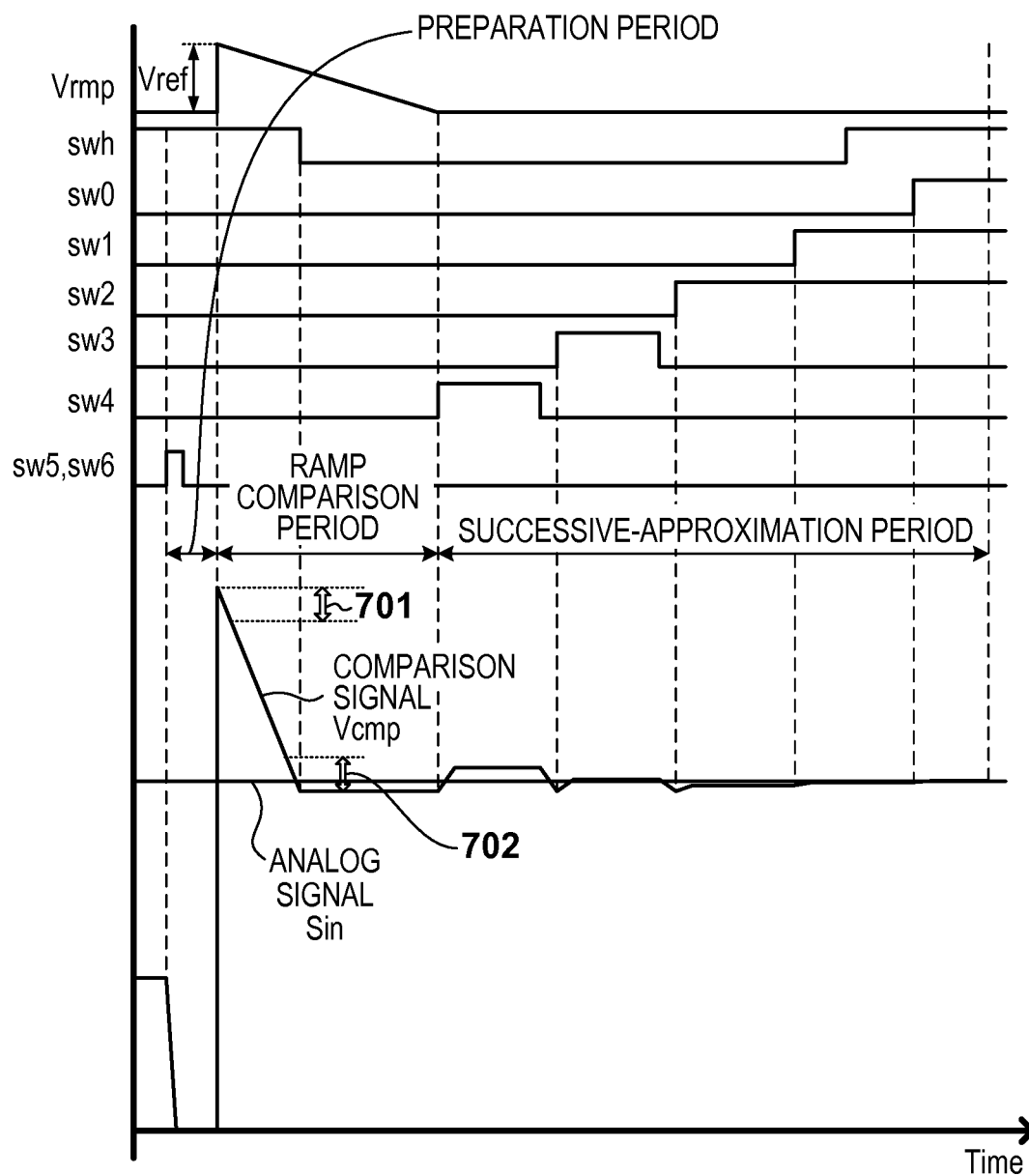
FIG. 7

FIG. 8

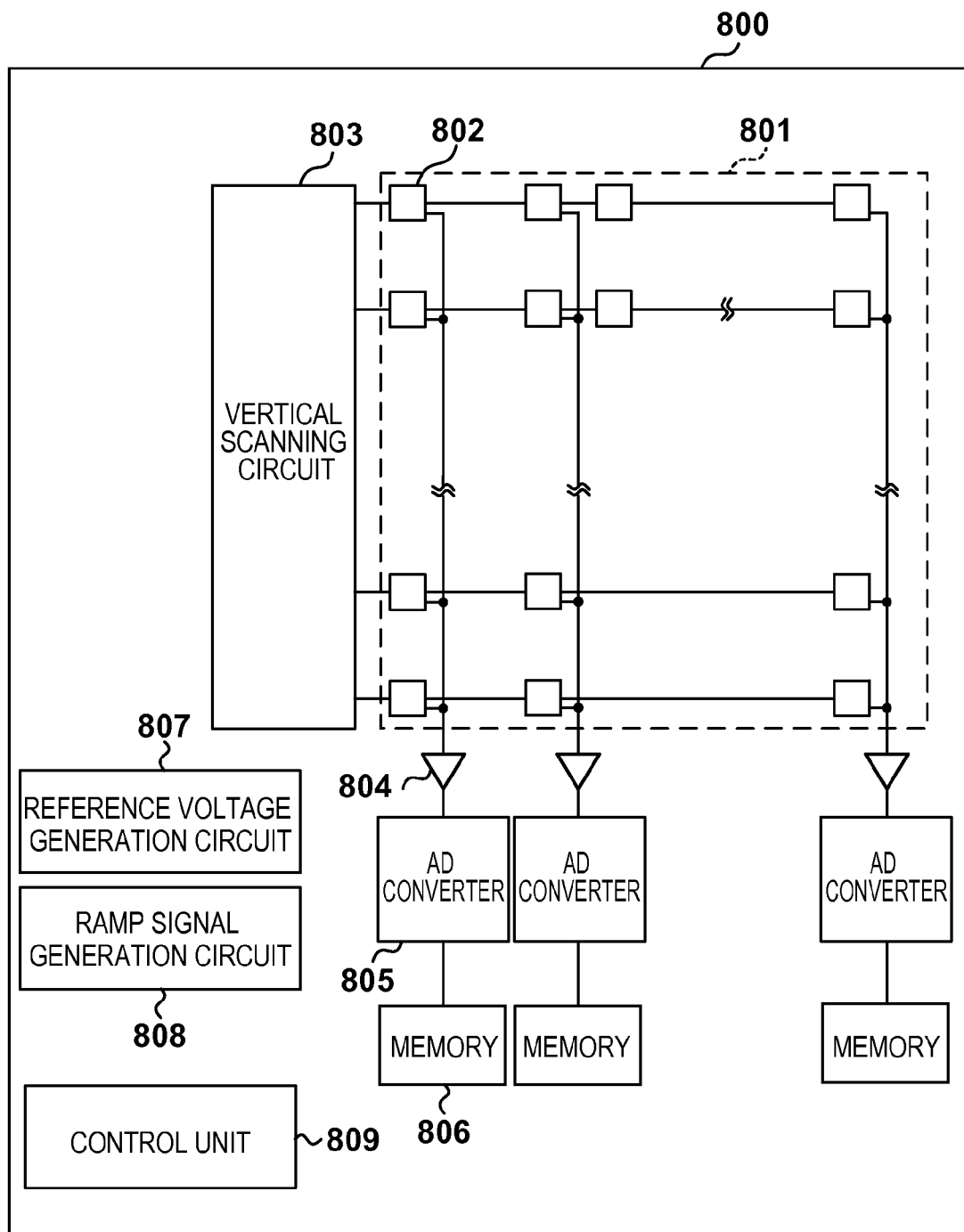


FIG. 9

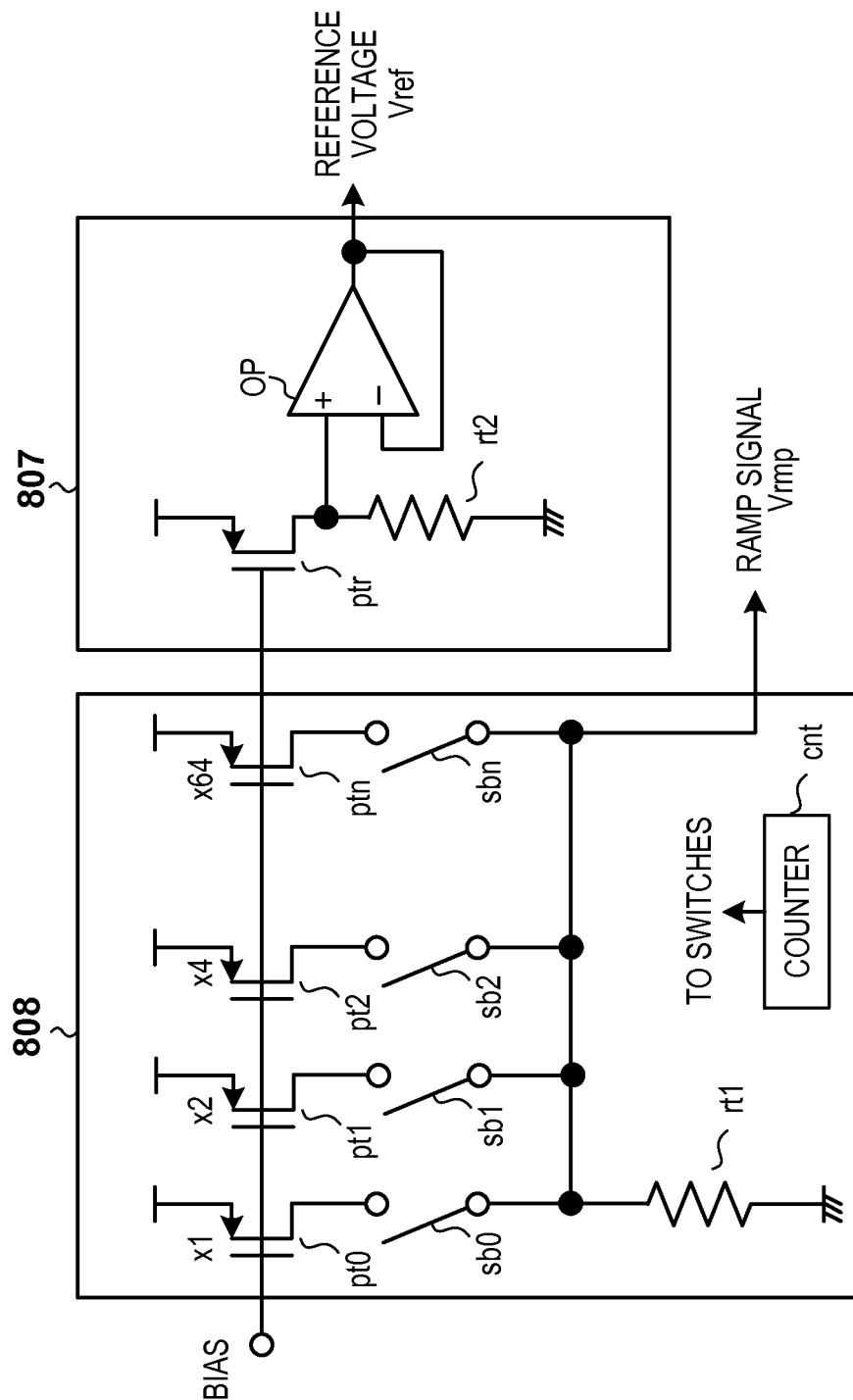
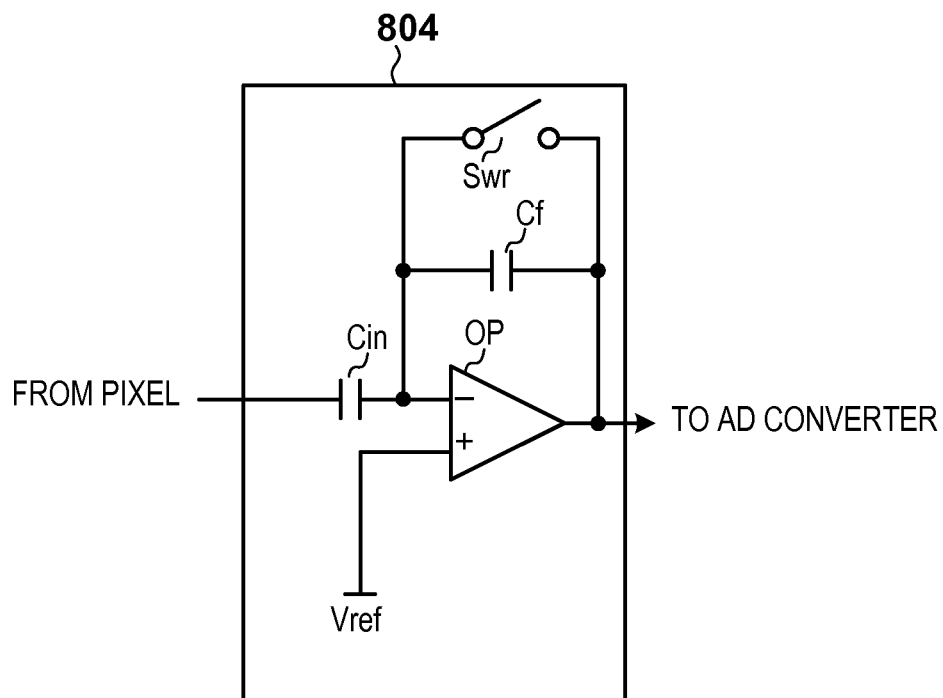
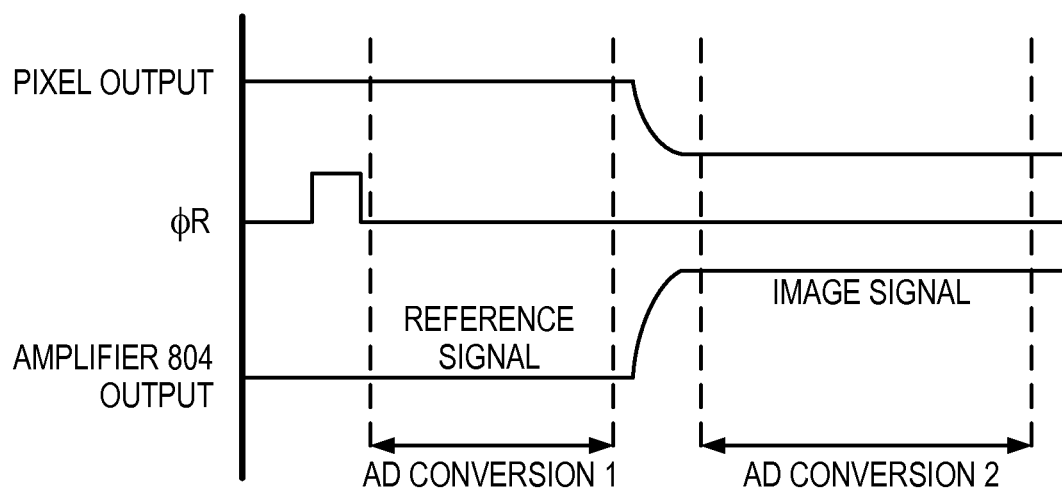


FIG. 10**FIG. 11**

SOLID-STATE IMAGING DEVICE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a solid-state imaging device.

2. Description of the Related Art

In general, solid-state imaging devices used for digital cameras or digital video include an AD converter to convert an image signal of analog values to digital values. Various types of AD converters are known, and one type of them is a ramp-type AD converter. In a ramp-type AD converter, relative magnitudes of an input analog signal and a ramp signal are compared using a comparator, and a period from the time when the ramp signal starts to change until the time when the output of the comparator inverts is measured to determine the digital value. Although ramp-type AD converters can be configured with a small scale circuit, this is not suitable for a high speed operation because $2^{(n-1)}$ clock cycles are required to perform the AD conversion with n-bit resolution. Another AD converter type is referred to as a successive-approximation AD converter. Successive-approximation AD converters, which include a plurality of capacitors having binary weighted capacitance values, change a comparison signal using the capacitors, and continue to halve the range where the analog value is included. Although successive-approximation AD converters are suitable for high speed operation because n-bit resolution is realized in n clock cycles, their circuit scale becomes large because the capacitance ratio of the capacitors (i.e. area ratio) becomes $1:2^{(n-1)}$ at a maximum.

Considering the current situation, Japanese Patent Laid-Open No. 2012-54913 proposes a hybrid type AD converter. In the AD converter, a sub-range including the digital value is determined using a plurality of capacitors, and the digital value is determined from the sub-range by using a ramp signal.

SUMMARY OF THE INVENTION

In a configuration described in Japanese Patent Laid-Open No. 2012-54913, a noise reduced signal, which is obtained by performing a correlated double sampling on a signal output from a photo-diode, is converted to a digital signal by an AD converter. However, in the method described in the Japanese Patent Laid-Open No. 2012-54913, since a digital signal is obtained, in which an offset component of the AD converter itself is superimposed, accuracy of the AD conversion may not be good enough. Therefore, an aspect of the present invention is to provide a technique which is beneficial for providing a high-speed and highly accurate AD converter.

An aspect of the present invention provides a solid-state imaging device comprising an AD converter configured to convert an analog value to a digital value, and a pixel array having a plurality of pixels configured to supply an analog signal to the AD converter, wherein the AD converter comprises: a generation circuit including a plurality of capacitors having binary weighted capacitance values, and a switch circuit configured to select at least one of the capacitors from the plurality of capacitors, the generation circuit being configured to generate a comparison signal according to a composite capacitance value of the at least one of the capacitors selected by the switch circuit; a comparator circuit configured to compare the analog value and the value of the comparison signal; a control circuit configured to perform a first comparison operation to narrow down a range including the analog value by performing a binary search, in which a value of the

comparison signal is changed by changing the composite capacitance value based on a comparison result of the comparator circuit, and to perform a second comparison operation to narrow down a range including the analog value based on a comparison result of the comparator circuit during a period when the comparison signal is changed at a constant rate, wherein the control circuit determines the digital value by performing one of the first comparison operation and the second comparison operation as a former comparison operation and then performing the other of the first comparison operation and the second comparison operation as a latter comparison operation in the range narrowed down by the former comparison operation, and the pixel array supplies, to the AD converter, a reference signal corresponding to a reset level of the pixel, and an image signal having image information, and the AD converter is configured to perform the latter comparison operation without performing the former comparison operation, when the reference signal is supplied.

Further features of the present invention will become apparent from the following description of exemplary embodiments (with reference to the attached drawings).

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of the specification, illustrate embodiments of the invention, and together with the description, serve to explain the principles of the invention.

FIG. 1 is a diagram illustrating an exemplary configuration of an AD converter according to an embodiment of the present invention.

FIG. 2 is a diagram illustrating an operating principle of the AD converter in FIG. 1.

FIG. 3 is a diagram illustrating an exemplary configuration of an AD converter according to another embodiment of the present invention.

FIG. 4 is a diagram illustrating an exemplary operation of the AD converter in FIG. 3.

FIG. 5 is a diagram illustrating another exemplary operation of the AD converter in FIG. 3.

FIG. 6 is a diagram illustrating an exemplary configuration of an AD converter according to yet another embodiment of the present invention.

FIG. 7 is a diagram illustrating an exemplary operation of the AD converter in FIG. 7.

FIG. 8 is a diagram illustrating an exemplary configuration of a solid-state imaging device according to an embodiment of the present invention.

FIG. 9 is a diagram illustrating an exemplary configuration of various generation circuits according to an embodiment of the present invention.

FIG. 10 is a diagram illustrating an exemplary configuration of an amplifier according to an embodiment of the present invention.

FIG. 11 is a diagram illustrating an exemplary operation of the amplifier in FIG. 10.

DESCRIPTION OF THE EMBODIMENTS

An exemplary embodiment of the present invention will be described in detail with reference to the accompanying drawings. Note that in the various embodiments, identical or corresponding elements are given the same reference numerals in the drawings, and descriptions thereof will not be repeated. Also a modification and a combination of each embodiment are possible, if appropriate.

Referring to FIG. 1, an exemplary circuit configuration of an AD converter **100** according to an embodiment of the present invention will be described. The AD converter **100** has an input terminal IN and an output terminal OUT, converts an analog signal Sin input from the input terminal IN to a digital signal Sout, and outputs the digital signal Sout from the output terminal OUT. The AD converter **100** converts the analog signal Sin to the digital signal Sout with 14-bit resolution. In other words, one of the integer numbers (digital value) that are at least 0 and no larger than $2^{14}-1$, corresponding to a value of the analog signal Sin (analog value), is output as the digital signal Sout.

The AD converter **100** further includes a generation circuit **101** to generate a comparison signal that is used for a comparison with the analog signal Sin. The generation circuit **101** includes a plurality of capacitors cp0 to cp4 having binary weighted capacitance values, and a plurality of switches sw0 to sw4 respectively connected to the capacitors cp0 to cp4. A switch circuit is configured where the plurality of switches sw0 to sw4 select one or more than one of the capacitors cp0 to cp4. A binary weight means a set of weights (capacitance values) that form a geometric progression of common ratio 2. In the example in FIG. 1, the capacitors cp0 to cp4 have capacitance values of 1C, 2C, 4C, 8C, 16C in that order. One electrode of each of the capacitors cp0 to cp4 is connected to a supply terminal SPL of the generation circuit **101**, and the other electrodes are respectively connected to the switches sw0 to sw4. One electrode of each of the switches sw0 to sw4 is connected to the capacitors cp0 to cp4, respectively, and the other electrode of each of the switches is toggled between a terminal A and a terminal B. The terminal A is supplied with a ground potential GND, and the terminal B is supplied with a reference voltage Vref. The reference voltage Vref is a constant voltage supplied from outside to the AD converter **100**, and is larger than the ground potential GND. When the switch sw0 is toggled to the terminal A, the ground potential GND is supplied to the capacitor cp0, and when the switch sw0 is toggled to the terminal B, the reference voltage Vref is supplied to the capacitor cp0. The other switches sw1-sw4 function similarly. By switching among the switches sw0 to sw4, a composite capacitance value of the capacitors connected between the supply terminal SPL and the reference voltage Vref changes, and the value of the comparison signal Vcmp output from the supply terminal SPL changes as a result.

The supply terminal SPL of the generation circuit **101** is further supplied with a ramp signal Vrm from outside the AD converter **100** through a capacitor cp5. The capacitor cp5 is a capacitor to adjust the magnitude of the ramp signal Vrm, and has a capacitance value of 1C. In other words, the capacitance value of the capacitor cp5 is equal to the minimum capacitance value of the group of capacitors cp0 to cp4 having binary weighted capacitance values. The value of the comparison signal Vcmp output from the supply terminal SPL changes also according to the change of the value of the ramp signal Vrm.

By combining the set of capacitors connected between the supply terminal SPL and the reference voltage Vref with the value of the ramp signal Vrm, the comparison signal Vcmp can have any value of at least the ground potential GND and at most the reference voltage Vref.

The AD converter **100** further includes a comparator CMP. The comparator CMP compares the value of the analog signal Sin with the value of the comparison signal Vcmp, and outputs a signal according to the comparison result. A non-inverting terminal of the comparator CMP is supplied with the analog signal Sin through a capacitor cp6, and an inverting

terminal of the comparator CMP is supplied with the comparison signal Vcmp from the supply terminal SPL of the generation circuit **101**. Accordingly, if the value of the analog signal Sin is at least the value of the comparison signal Vcmp, High is output, and if the value of the analog signal Sin is less than the value of the comparison signal Vcmp, Low is output. Although, in this example, High is output if the value of the analog signal Sin is equal to the value of the comparison signal Vcmp, Low may be output instead. The capacitor cp6 adjusts the value of the analog signal Sin to a range where the comparison with the comparison signal Vcmp is possible. For the sake of simplifying explanations, this embodiment handles a case in which the value of the analog signal Sin is at least the ground potential GND and not larger than the reference voltage Vref, and a signal having the same magnitude as the analog signal Sin is supplied to the non-inverting terminal of the comparator CMP.

In the example in FIG. 1, although the analog signal Sin is supplied to the non-inverting terminal of the comparator CMP, and the comparison signal Vcmp is supplied to the inverting terminal of the comparator CMP, other configurations may be possible as long as the magnitude comparison between the value of the analog signal Sin and the value of the comparison signal Vcmp is possible. For example, a difference between the analog signal Sin and the comparison signal Vcmp may be supplied to the non-inverting terminal of the comparator CMP, and the ground potential GND may be supplied to the inverting terminal of the comparator CMP.

The AD converter **100** further includes switches sw5 and sw6. When these switches sw5 and sw6 are made conductive, the ground potential GND is supplied to the non-inverting terminal and the inverting terminal of the comparator CMP, and the comparator CMP is reset.

The comparator CMP further includes a control circuit **102** and a counter **103**. The control circuit **102** is supplied with a comparison result from the comparator CMP. The control circuit **102** generates a digital signal Sout based on the comparison result, and outputs the digital signal Sout from an output terminal OUT. The control circuit **102** also sends control signals to the switches sw0 to sw6 to switch their state. The counter **103** starts counting following an instruction from the control circuit **102**, and returns the current count value to the control circuit **102** following a subsequent instruction by the control circuit **102**.

Next, referring to a timing chart in FIG. 2, a principle of an AD conversion operation by the AD converter **100** will be described. The AD converter **100** executes a first comparison operation (hereinafter referred to as "successive approximation"), in which a binary search is performed by changing the comparison signal Vcmp using the capacitors cp0 to cp4 in a successive-approximation period (first period), and determines the upper five bits of the digital signal Sout. Next, the AD converter **100** executes a second comparison operation (hereinafter referred to as "ramp comparison"), in which a comparison with the analog signal Sin is performed by changing the comparison signal Vcmp using the ramp signal Vrm in a ramp comparison period (second period), and determines the lower nine bits of the digital signal Sout. In FIG. 2, Vrm represents a value of the ramp signal Vrm. The value of the ramp signal Vrm is equal to the ground potential GND until the ramp comparison period starts, and monotonously changes until it becomes equal to the reference voltage Vref in the ramp comparison period. In the example in FIG. 2, the value of the ramp signal Vrm increases at a fixed rate, in other words, it increases by an equal value at every unit time. In the AD converter **100**, the value of the ramp signal Vrm increases by $V_{ref}/2^9$ at every clock cycle. Accordingly, the

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AD converter **100** can perform the comparison between the analog signal S_{in} and the comparison signal V_{cmp} in the ramp comparison period with 9-bit resolution. In other words, since the control circuit **102** can narrow down the range that includes the value of the analog signal S_{in} to the range having a width of $V_{ref}/2^9$ by the ramp comparison, it determines a digital value corresponding to that range.

In this embodiment, the change amount of the ramp signal V_{rmp} is equal to the reference voltage V_{ref} . By supplying such a ramp signal V_{rmp} to the AD converter **100**, the capacitance value of the capacitor $cp5$ which is supplied with the ramp signal V_{rmp} can be set such that its ratio to the capacitance values of the binary weights becomes an integer. In a monolithic IC, capacitors with weights (capacitance value) having a ratio of an integer number can be easily configured, so that the configuration of the AD converter **100** is advantageous because the change amount of the comparison signal V_{cmp} in the ramp comparison can be set with just the capacitance value of the capacitor $cp5$.

In FIG. 2, $sw0$ to $sw6$ represent the value of control signals supplied to the switches $sw0$ to $sw6$ by the control circuit **102**. The switches $sw0$ to $sw4$ are toggled to the terminal B when the control signal that is supplied is High, and are toggled to the terminal A when the control signal is Low. The switches $sw5$ and $sw6$ are made conductive when the supplied control signal is High, and made non-conductive when the control signal is Low. In the lower part of FIG. 2, the analog signal S_{in} and the comparison signal V_{cmp} are shown. In FIG. 2, a case in which the value of the analog signal S_{in} corresponds to a digital value 3382 in decimal (00 1101 0011 0110, in binary), is given as an example.

Next, an AD-conversion operation of the AD converter **100** will be described in chronological order. In a preparation period, the control circuit **102** sets the control signals supplied to the switches $sw0$ to $sw4$ to Low, and sets the control signals supplied to the switches $sw5$ and $sw6$ to High. Accordingly, the non-inverting terminal and the inverting terminal of the comparator CMP are reset to the ground potential GND, and the value of the comparison signal V_{cmp} is made equal to the ground potential GND. After that, the control circuit **102** sets the control signals supplied to the switches $sw5$ and $sw6$ to Low. In the following operation, the non-inverting terminal of the comparator CMP continues to be supplied with the analog signal S_{in} .

Next, when the successive-approximation period starts, the control circuit **102** changes the control signal supplied to the switch $sw4$ to High. Accordingly, the switch $sw4$ is toggled to the terminal B, and the supply terminal SPL of the generation circuit **101** is supplied with the reference voltage V_{ref} through the capacitor $cp4$ having the largest capacitance value among the binary weights. As a result, the comparison signal V_{cmp} increases by $V_{ref}/2$ and the value of the comparison signal V_{cmp} becomes equal to $V_{ref}/2$. The control circuit **102** determines that the value of the analog signal S_{in} is less than the value of the comparison signal V_{cmp} ($V_{ref}/2$) based on the comparison result by the comparator CMP, and sets the control signal supplied to the switch $sw4$ back to Low. As a result, the value of the comparison signal V_{cmp} returns to the ground potential GND. This comparison result means that the MSB (the 13-th bit from the LSB, if the LSB is assumed to be the 0-th bit) of the digital signal S_{out} is 0.

Next, the control circuit **102** changes the control signal supplied to the switch $sw3$ to High. Accordingly, the supply terminal SPL of the generation circuit **101** is supplied with the reference voltage V_{ref} through the capacitor $cp3$ having the second largest capacitance value among the binary weights. As a result, the comparison signal V_{cmp} increases by $V_{ref}/4$

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and the value of the comparison signal V_{cmp} becomes equal to $V_{ref}/4$. The control circuit **102** determines that the value of the analog signal S_{in} is less than the value of the comparison signal V_{cmp} ($V_{ref}/4$) based on the comparison result by the comparator CMP, and sets the control signal supplied to the switch $sw3$ back to Low. As a result, the value of the comparison signal V_{cmp} returns to the ground potential GND. This comparison result means that the 12-th bit of the digital signal S_{out} is 0.

Next, the control circuit **102** changes the control signal supplied to the switch $sw2$ to High. Accordingly, the supply terminal SPL of the generation circuit **101** is supplied with the reference voltage V_{ref} through the capacitor $cp2$ having the third largest capacitance value among the binary weights. As a result, the comparison signal V_{cmp} increases by $V_{ref}/8$ and the value of the comparison signal V_{cmp} becomes equal to $V_{ref}/8$. The control circuit **102** determines that the value of the analog signal S_{in} is larger than the value of the comparison signal V_{cmp} ($V_{ref}/8$) based on the comparison result by the comparator CMP, and keeps the control signal supplied to the switch $sw2$ High. As a result, the value of the comparison signal V_{cmp} is kept at $V_{ref}/8$. This comparison result means that the 11-th bit of the digital signal S_{out} is 1.

Next, the control circuit **102** changes the control signal supplied to the switch $sw1$ to High. Accordingly, the supply terminal SPL of the generation circuit **101** is supplied with the reference voltage V_{ref} through the capacitors $cp1$ having the 4-th largest capacitance value among the binary weights, and $cp2$. As a result, the comparison signal V_{cmp} increases by $V_{ref}/16$ and the value of the comparison signal V_{cmp} becomes equal to $V_{ref}*3/16$. The control circuit **102** determines that the value of the analog signal S_{in} is larger than the value of the comparison signal V_{cmp} ($V_{ref}*3/16$) based on the comparison result by the comparator CMP, and keeps the control signal supplied to the switch $sw1$ High. As a result, the value of the comparison signal V_{cmp} is kept at $V_{ref}*3/16$. This comparison result means that the 10-th bit of the digital signal S_{out} is 1.

Finally, the control circuit **102** changes the control signal supplied to the switch $sw0$ to High. Accordingly, the supply terminal SPL of the generation circuit **101** is supplied with the reference voltage V_{ref} through the capacitors $cp0$ having the 5-th largest capacitance value among the binary weights, $cp1$ and $cp2$. As a result, the comparison signal V_{cmp} increases by $V_{ref}/32$ and the value of the comparison signal V_{cmp} becomes equal to $V_{ref}*7/32$. The control circuit **102** determines that the value of the analog signal S_{in} is less than the value of the comparison signal V_{cmp} ($V_{ref}*7/32$) based on the comparison result by the comparator CMP, and returns the control signal supplied to the switch $sw0$ to Low. As a result, the value of the comparison signal V_{cmp} returns to $V_{ref}*3/16$. This comparison result means that the 9-th bit of the digital signal S_{out} is 0.

As the result of the successive-approximation described above, the control circuit **102** can narrow down the range that includes the value of the analog signal S_{in} to the range between at least $V_{ref}*3/16$ and less than $V_{ref}*7/32$. As a result, the control circuit **102** determines that the upper bits of the digital signal S_{out} are 00110. In other words, the control circuit **102** specifies that the value of the digital signal S_{out} is included in the range which is at least 00 1100 0000 0000, and not more than 00 1101 1111 1111, in binary. Thus, in the ramp comparison performed successively, the AD converter **100** determines the value of the digital signal S_{out} from the narrowed down range.

When the ramp comparison starts, the ramp signal V_{rmp} starts increasing. The control circuit **102** causes the counter

103 to start counting from the start of the increase of the ramp signal V_{rmp} . A supply source of the ramp signal V_{rmp} may start increasing the ramp signal V_{rmp} in response to a request from the control circuit **102**, or may start at a predetermined timing without receiving the request. While the ramp signal V_{rmp} changes from the ground potential GND to the reference voltage V_{ref} , the value of the comparison signal V_{cmp} also changes from $V_{\text{ref}} \times 3/16$ to $V_{\text{ref}} \times 7/32$. The control circuit **102** obtains a count value from the counter **103** when the output from the comparator CMP inverted. This count value corresponds to the value that results from subtracting $V_{\text{ref}} \times 3/16$ from the value of the analog signal S_{in} , and in the example in FIG. 2, it is 1 0011 0110 (in binary). The value coincides with the lower bits of the digital signal S_{out} . The control circuit **102** can further narrow down the range including the value of the analog signal S_{in} by the ramp comparison. The control circuit **102** acquires the digital value corresponding to the further narrowed down range, determines that the digital value, which corresponds to the value of the analog signal S_{in} , is 3382, and outputs this value from the output terminal OUT.

As described above, since the AD converter **100** determines the upper bits of the digital signal S_{out} by successive-approximation, the time required for an AD conversion can be reduced compared with an AD converter which determines all bits by ramp comparison. Also, since successive-approximation is performed using a set of capacitors having binary weighted capacitance values, the circuit scale for the successive-approximation can be reduced. Although the example described above relates to a case in which the ramp signal V_{rmp} increases monotonously, the ramp signal V_{rmp} may also decrease monotonously. In this case, the comparison signal V_{cmp} decreases monotonously from the upper limit to the lower limit of the range which is narrowed down by the successive-approximation.

Next, referring to FIG. 8, an exemplary configuration of a solid-state imaging device **800** according to an embodiment will be described. The solid-state imaging device **800** may have the components shown in FIG. 8. A pixel array **801** is provided with a plurality of pixels **802** in an array. A vertical scanning circuit **803** scans the pixels **802** row by row and controls a timing to output a pixel signal to a vertical signal line shared by a column of pixels. An amplifier **804** amplifies a signal from the vertical signal line, and outputs it to an AD converter **805**. The amplifier **804** is, for example, a variable gain amplifier. The AD converter **805** is one of the AD converters **100**, **300**, or **600** described in this specification. The AD converter **805** converts the analog pixel signal supplied by the amplifier **804** to a digital pixel signal and stores it in a memory **806**. A reference voltage generation circuit **807** supplies a reference voltage V_{ref} to the AD converter **805**, and a ramp signal generation circuit **808** supplies a ramp signal V_{rmp} to the AD converter **805**. A control unit **809** supplies clock signals and control signals to each of the components of the solid-state imaging device **800**.

In the solid-state imaging device **800**, the signal from the pixels **802** is output, in general, by a pixel amplifier such as a pixel source follower. In this case, the pixels **802** output a reference signal corresponding to a reset level of the pixels, and an image signal which includes image information after charges have been transferred from a photoelectric conversion element, as analog signals. In this embodiment, the AD converter **805** performs an AD-conversion on the reference signal and on the image signal, respectively, and obtains a difference between these two signals. In this manner, a CDS (correlated double sampling) operation to reduce a fixed-

pattern noise specific to the pixels **802** is performed, and at the same time, a fixed-pattern noise specific to the AD converter **805** is reduced.

In the digital signal obtained by performing the AD-conversion on the reference signal, the fixed-pattern noise (offset) specific to the AD converter **805** is superimposed thereon. Similarly, in the digital signal obtained by performing the AD-conversion on the image signal, the offset specific to the AD converter **805** is superimposed thereon. Therefore, by taking the difference between these two digital signals, the fixed-pattern noise specific to the pixels and the fixed-pattern noise specific to the AD converter **805** can be reduced simultaneously.

The value of the reference signal is small compared with the value of the image signal. Therefore, the AD converter **805** performs the entire AD-conversion operation described above on the image signal, and omits a part of the AD-conversion operation on the reference signal. For example, let us assume that the AD converter **805** is the AD converter **100**. When the AD converter **100** performs an AD-conversion on the reference signal, the control circuit **102** may omit the successive-approximation, and may perform only the ramp comparison. In particular, it is possible that the control circuit **102** does not perform the successive-approximation, and determines that the analog signal S_{in} is included in the minimum range narrowed down by the successive-approximation which is at least 0 and less than $V_{\text{ref}}/32$, and the ramp comparison may be performed in this range. And after the completion of the ramp comparison, the control circuit **102** determines the digital value assuming that the upper bits decided by the successive-approximation are all 0s. Therefore the time required for the successive-approximation can be reduced. Also, the AD converter **100** may perform only a part of the successive-approximation process. For example, supposing preliminarily that the upper 3 bits determined by using the capacitors cp2-cp4 are 0s, the successive-approximation may be started from the 4-th most significant bit using the capacitor cp2. Which range of the reference signal is subjected to the AD-conversion may be designed as appropriate, depending on the characteristics of the pixels **802** or the like.

Furthermore, the case is considered that, if the AD converter **805** is the AD converter **100** and the AD-conversion is performed on the reference signal, the control circuit **102** omits the successive-approximation and performs only the ramp comparison. In addition, the counter **103** is assumed to have a switching function between an up-count and down-count. In this case, the control circuit **102** may cause the counter **103** to decrement when performing an AD-conversion on the reference signal, and may cause the counter **103** to increment when performing an AD-conversion on the image signal. Accordingly, as the digital image signal that is output from the AD converter **100**, a value obtained by subtracting the reference signal is output. In this way, since the AD converter **100** performs the CDS function automatically, conversion errors of the AD converter caused by a variation of the capacitors or the like can be reduced, and the time to subtract the reference signal from the image signal is reduced, in addition.

Here, although an explanation is given for a solid-state imaging device as an example, there is no limitation to solid-state imaging devices, and an offset caused by the characteristics of the AD converter can be reduced, by subtracting an AD-conversion result of a reference signal supplied by a signal source, from an AD-conversion result of a signal in which a signal component is superimposed on the reference signal. In particular, in a configuration where an AD converter is provided for each column of pixels as in the solid-state

imaging device **800**, since a difference of offsets among AD converters appears as a stripe-shaped noise in an image acquired, it is effective to reduce the offset of the AD converter.

Next, an AD converter according to another embodiment of the present invention will be described. In the previous embodiment, an offset of the AD converter is reduced using a reference signal corresponding to a reset level of a pixel, and an image signal including image information after charges have been transferred from a photoelectric conversion element. In this embodiment, an offset of an AD converter is reduced by using an output from an amplifier. Here, a case in which, in the solid-state imaging device **800** in FIG. **8**, the amplifier **804** is a capacitive feedback type amplifier will be described.

FIG. **10** shows an exemplary configuration of an amplifier according to the embodiment. In FIG. **10**, the amplifier **804** includes an operational amplifier OP, an input capacitance C_{in} , a feedback capacitor C_f , and a reset switch Sw_r . A gain of the amplifier **804** can be made variable by making variable at least one of the capacitance values of the input capacitor C_{in} and the feedback capacitor C_f .

FIG. **11** is a timing chart illustrating an exemplary operation of the amplifier **804** in FIG. **10**. First, a signal ϕ_R is set to High to turn on the reset switch Sw_r . Accordingly, both electrodes of the feedback capacitor C_f are reset to V_{ref} . In this time period, a pixel signal for the case that a pixel is reset is input to the amplifier **804**. Next, an AD-conversion is performed using the output of the amplifier **804** for the case that the signal ϕ_R is set to Low as a reference signal (AD-conversion 1).

After the completion of the AD-conversion performed on the reference signal, an image signal of the pixel is input to the amplifier **804**. Accordingly, noise caused by the pixel is reduced by the input capacitance C_{in} , and an amplified image signal is output from the amplifier **804**. An AD-conversion is performed on the output of the amplifier **804** as an image signal (AD-conversion 2).

Next, by taking a difference between the digital signal obtained in the AD-conversion 1 and the digital signal obtained in the AD-conversion 2, an offset specific to the AD converter can be reduced. The method of taking the difference may be one utilizing a counter which is capable of switching between an up-count and a down-count described in the above embodiment.

In the following, referring to FIG. **3**, an exemplary circuit configuration of an AD converter **300** according to another embodiment will be described. The AD converter **300** is different from the AD converter **100** described above in the point that it has a generation circuit **301** and a control circuit **302** instead of the generation circuit **101** and the control circuit **102**. In the following, the AD converter **300** is described focusing on the difference from the AD converter **100**. The AD converter **300** converts an analog signal S_{in} to a digital signal S_{out} with 13-bit resolution. In other words, it outputs an integer number which is at least 0 and not more than $2^{13}-1$ as the digital signal S_{out} (digital value) corresponding to the value of the analog signal S_{in} (analog value). If an AD converter is operated at high speed, a comparator may misjudge due to insufficient settling or the like. The AD converter **300** according to the embodiment performs a correct AD-conversion even in a case where the comparator CMP has misjudged.

The generation circuit **301** further includes a capacitor c_{pa} and a switch sw_a along with the components of the generation circuit **101**. One of the electrodes of the capacitor c_{pa} is connected to a supply terminal SPL of the generation circuit

301, and the other electrode is connected to the switch sw_a . One end of the switch sw_a is connected to the capacitor c_{pa} , and the other end is toggled between a terminal A and a terminal B. A ground potential GND is supplied to the terminal A and a reference voltage V_{ref} is supplied to the terminal B. When the switch sw_a is toggled to the terminal A, the ground potential GND is supplied to the capacitor c_{pa} , and when the switch sw_a is toggled to the terminal B, the reference voltage V_{ref} is supplied to the capacitor c_{pa} . The capacitance value of the capacitor c_{pa} is $C/2$. In other words, the capacitance value of the capacitor c_{pa} is half the minimum capacitance value of the group of capacitors cp_0 to cp_4 having the binary weighted capacitance values. Furthermore, the capacitance value of the capacitor CP_5 in the generation circuit **301** is $2C$. In other words, the capacitance value of the capacitor cp_5 is the same as the second smallest capacitance value of the group of capacitors cp_0 to cp_4 having the binary weighted capacitance values.

Next, referring to timing charts in FIGS. **4** and **5**, an example of an AD-conversion operation by the AD converter **300** will be described. Also in FIGS. **4** and **5**, like in FIG. **2**, the value of the ramp signal V_{rmp} is equal to the ground potential GND until the ramp comparison period starts, and monotonously changes until it becomes equal to the reference voltage V_{ref} in the ramp comparison period. Also, in the AD converter **300**, the value of the ramp signal V_{rmp} increases by $V_{ref}/2^9$ at every clock cycle. Accordingly, the AD converter **300** can perform the comparison in 9-bit resolution between the analog signal S_{in} and the comparison signal V_{cmp} in the ramp comparison period. In FIGS. **4** and **5**, sw_a shows the value of a control signal supplied to the switch sw_a by the control circuit **302**. The switch sw_a is toggled to the terminal B when the control signal that is supplied is High, and is toggled to the terminal A when the control signal is Low.

First, referring to FIG. **4**, an example of a case where the comparator CMP does not misjudge will be described. In FIG. **4**, a case in which the value of the analog signal S_{in} corresponds to a digital value 1718 in decimal (0 0110 1011 0110, in binary), is given as an example. In a preparation period, the control circuit **302** sets control signals supplied to the switches sw_0 to sw_4 to Low, and sets control signals supplied to the switch sw_a , sw_5 and sw_6 to High. Accordingly, the non-inverting terminal and the inverting terminal of the comparator CMP are reset to the ground potential GND, and the value of the comparison signal V_{cmp} is made equal to the ground potential GND. Next, the control circuit **302** sets the control signals supplied to the switches sw_5 and sw_6 to Low. In the following operations, the non-inverting terminal of the comparator CMP continues to be supplied with the analog signal S_{in} . Also, the control circuit **302** keeps the control signal supplied to the switch sw_a High in the successive-approximation period.

Next, the operation for the successive-approximation period is performed. Since the successive-approximation performed by the AD converter **300** is the same as that of the AD converter **100**, its explanation will be omitted. After the completion of the successive-approximation, the control circuit **302** narrows down the range that includes the value of the analog signal S_{in} to the range between at least $V_{ref} \cdot 3/16$ and less than $V_{ref} \cdot 7/32$ (range designated by an arrow **401**). In other words, the control circuit **302** determines the upper bits of the digital signal S_{out} to be 00110. However, if the comparator CMP misjudged in the successive-approximation, the value of the analog signal S_{in} may not be included in this range. Thus, the control circuit **302** performs a ramp comparison in a range that is larger than this range. In particular, it compares the value of the analog signal S_{in} with the value

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of the comparison signal V_{cmp} which changes in a range that is wider than the range determined by the successive-approximation by $V_{ref}/64$ at the both ends, that is the range of at least $V_{ref} \cdot 11/64$ and less than $V_{ref} \cdot 15/64$ (range designated by an arrow 402). In other words, the control circuit 302 narrows down the value of the digital signal S_{out} , in order to correct the misjudgment, in the range of at least 0 0101 1000 0000 and no larger than 0 0111 0111 1111 in binary. In order to perform the comparison in this range, the control circuit 302 switches the control signal supplied to the switch swa to Low after the completion of the successive-approximation. As a result, the voltage supplied to the switch swa switches from the reference voltage V_{ref} to the ground potential GND, and the comparison signal V_{cmp} is reduced by $V_{ref}/64$ to $V_{ref} \cdot 11/64$.

When the ramp comparison period starts, the comparison signal V_{cmp} increases from $V_{ref} \cdot 11/64$ along with the increase of the ramp signal V_{rmp} . Since the capacitance value of the capacitor $cp5$ is $2C$ in the AD converter 300, when the ramp signal increases by V_{ref} , the comparison signal V_{cmp} increases by $V_{ref}/16$. Accordingly, the comparison signal V_{cmp} varies from $V_{ref} \cdot 11/64$ to $V_{ref} \cdot 15/64$ in the ramp comparison period. The count value when the output from the comparator CMP inverts corresponds to the value obtained by subtracting $V_{ref} \cdot 11/64$ from the value of the analog signal S_{in} , and is 1 0011 0110 (binary), in the example in FIG. 4. Thus, the control circuit 302 determines the digital signal S_{out} by performing the following calculation.

$$\text{digital value} = (\text{upper bits}) \cdot 256 - 128 + (\text{lower bits})$$

Here, the upper bits are the value determined by the successive-approximation, and are 6 in decimal for the example in FIG. 4. “ $\cdot 256$ ” means an operation of shifting the upper bits by 8 bits to the left. “ -128 ” corresponds to the value obtained by subtracting the value of the comparison signal V_{cmp} ($V_{ref}/64$) after the completion of the successive-approximation. “lower bits” are determined by the ramp comparison, and are 310 in decimal in the example in FIG. 4. Accordingly, in the example in FIG. 4, $6 \cdot 256 - 128 + 310 = 1718$ is the determined digital value.

Next, referring to FIG. 5, an exemplary case in which the comparator CMP misjudged will be described. In FIG. 5, an exemplary case in which the value of the analog signal S_{in} corresponds to the digital value of 1718 in decimal (0 0110 1011 0110, in binary) will be described as in FIG. 4. Since the explanation for the preparation period is the same as that in FIG. 4, it will be omitted.

Let us assume that the comparator CMP misjudged when the control circuit 302 changed the control signal supplied to the switch $sw0$ to High in the successive-approximation. In other words, the comparator CMP outputs a reversed result even though the analog signal is less than the value of the comparison signal V_{cmp} ($V_{ref} \cdot 7/32$). Accordingly, the control circuit 302 determines that the value of the analog signal S_{in} is larger than the value of the comparison signal V_{cmp} ($V_{ref} \cdot 7/32$) based on the comparison result by the comparator CMP, and keeps the control signal supplied to the switch $sw0$ at High. Therefore, the value of the comparison signal V_{cmp} is kept at $V_{ref} \cdot 7/32$. This comparison result means that the 10-th least significant bit of the digital signal S_{out} is 1.

After the completion of the successive-approximation, the control circuit 302 narrows down the range that includes the value of the analog signal S_{in} to the range between at least $V_{ref} \cdot 7/32$ and less than $V_{ref}/4$ (range designated by an arrow 501). In other words, the control circuit 302 determines the upper bits of the digital signal S_{out} to be 00111. However, since the comparator CMP misjudged in the successive-ap-

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proximation, the value of the analog signal S_{in} is not included in this range. Since the control circuit 302 in the AD converter 300 according to this embodiment performs the ramp comparison in the range larger than this range, the misjudgment can be corrected. In particular, it compares the value of the analog signal S_{in} with the value of the comparison signal V_{cmp} which changes in the range wider than the range determined by the successive-approximation by $V_{ref}/64$ at the both ends, that is, at least $V_{ref} \cdot 13/64$ and less than $V_{ref} \cdot 17/64$ (range designated by an arrow 502). In other words, the control circuit 302 narrows down the value of the digital signal S_{out} , in order to correct the misjudgment, in the range of at least 0 0110 1000 0000 and no larger than 0 1000 0111 1111 in binary. In order to perform the comparison in this range, the control circuit 302 switches the control signal supplied to the switch swa to Low after the completion of the successive-approximation. As a result, the voltage supplied to the switch swa switches from the reference voltage V_{ref} to the ground potential GND, and the value of the comparison signal V_{cmp} is reduced by $V_{ref}/64$ to $V_{ref} \cdot 13/64$.

When the ramp comparison period starts, the comparison signal V_{cmp} increases from $V_{ref} \cdot 13/64$ along with the increase of the ramp signal V_{rmp} . Since the capacitance value of the capacitor $cp5$ is $2C$ in the AD converter 300, when the ramp signal increases by V_{ref} , the comparison signal V_{cmp} increases by $V_{ref}/16$. Accordingly, the value of the comparison signal V_{cmp} varies from $V_{ref} \cdot 13/64$ to $V_{ref} \cdot 17/64$ in the ramp comparison period. The count value when the output from the comparator CMP inverts corresponds to the value obtained by subtracting $V_{ref} \cdot 13/64$ from the value of the analog signal S_{in} , and is 0 0011 0110 (binary), in an example in FIG. 4. Thus, the control circuit 302 determines the digital signal S_{out} by performing the same calculation as described above, and $7 \cdot 256 - 128 + 54 = 1718$ is determined to be the digital value. This value is equal to the value when no misjudgment has occurred as described in FIG. 4.

As described above, the AD converter 300 has an advantage that it is capable of correcting a misjudge by the comparator CMP along with the advantages of the AD converter 100 described above. In the above example, the comparison range in the ramp comparison is set to be a range that is wider than the range determined by the successive-approximation by $V_{ref}/64$ at the both ends. Accordingly, the AD converter 300 can accommodate misjudgments by the comparator CMP of errors less than $V_{ref}/64$. Although errors in a wider range can be accommodated by making the comparison range wider in the ramp comparison, either the resolution of the AD-conversion is reduced or a longer time is required for the ramp comparison. Thus, the comparison range in the ramp comparison may be set to the double of the range narrowed down by the successive-approximation, as in the example described above, or may be set less than double. Also, although in the example described above, the comparison range is made wider by the same amount at the both ends, these two widths may be different, or only one of the upper side or the lower side may be widened.

Next, referring to FIG. 6, an exemplary circuit configuration of an AD converter 600 according to another embodiment will be described. The AD converter 600 is different from the AD converter 100 described above in the point that it has a generation circuit 601 and a control circuit 602 instead of the generation circuit 101 and the control circuit 102. In the following, the AD converter 600 is described focusing on the difference from the AD converter 100. The AD converter 600 converts an analog signal S_{in} to a digital signal S_{out} of 9-bit resolution. In other words, it outputs an integer number which is at least 0 and not more than $2^9 - 1$ as the digital signal S_{out}

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(digital value) corresponding to the value of the analog signal Sin (analog value). The AD converter 600 performs the successive-approximation to determine the digital signal Sout after narrowing down the range which includes the value of the analog signal Sin by the ramp comparison.

The generation circuit 601 further includes a capacitor cph and a switch swh along with the components of the generation circuit 101. The switch swh is connected between the capacitor cp5 and the ramp signal V_{mp}. One of the electrodes of the capacitor cph is connected to a node between the switch swh and the capacitor cp5, and the other electrode is supplied with the ground potential GND. The capacitance value of the capacitor cph is 64C. In other words, the capacitance value of the capacitor cph is four times larger than the maximum capacitance value of the group of capacitors cp0 to cp4 having the binary weighted capacitance values.

In the following, referring to timing chart in FIG. 7, an example of an AD-conversion operation by the AD converter 600 will be described. The value of the ramp signal V_{mp} is equal to the ground potential GND until the ramp comparison period starts, and monotonously changes from the reference voltage V_{ref} to the ground potential GND at a constant rate in the ramp comparison period. In the example in FIG. 7, the ramp signal V_{mp} decreases linearly. In the AD converter 600, the value of the ramp signal V_{mp} decreases by $V_{ref}/2^4$ at every clock cycle. Accordingly, the AD converter 600 can perform the comparison between the analog signal Sin and the comparison signal V_{cmp} in the ramp comparison period with 4-bit resolution. As the result, the range including the value of the analog signal Sin can be narrowed down to the range with the width of $V_{ref}/2^4$. In FIG. 7, swh indicates the value of a control signal supplied to the switch swh by the control circuit 602. The switch swh is made conductive when the control signal that is supplied is High, and is made non-conductive when the control signal is Low.

In the following, an AD-conversion operation of the AD converter 600 will be described in chronological order. In a preparation period, the control circuit 602 sets the control signals supplied to the switches sw0 to sw4 to Low, and sets the control signals supplied to the switches sw5, and sw6 to High. Accordingly, the non-inverting terminal and the inverting terminal of the comparator CMP are reset to the ground potential GND, and the value of the comparison signal V_{cmp} is made equal to the ground potential GND. After that, the control circuit 602 sets the control signals supplied to the switches sw5 and sw6 to Low. In the following operation, the non-inverting terminal of the comparator CMP continues to be supplied with the analog signal Sin. Also, the control circuit 602 keeps the control signal supplied to the switch swh at High from the start of the ramp comparison period.

When the ramp comparison period starts, the ramp signal V_{mp} start decreasing after it increased to V_{ref}. The control circuit 602 causes the counter 103 to start counting from the start of the decrease of the ramp signal V_{mp}. While the ramp signal V_{mp} changes from the reference voltage V_{ref} to the ground potential GND, the value of the comparison signal V_{cmp} decreases from the reference voltage V_{ref} by $V_{ref}/16$ (range designated by an arrow 701) at every clock cycle (at every unit time interval). The control circuit 602 obtains a count value from the counter 103 when the output from the comparator CMP is inverted, and switches the control signal supplied to the switch swh to Low. Accordingly, the value of the comparison signal V_{cmp} at this moment is sampled by the capacitor cph. The obtained count number corresponds to the upper bits of the digital signal Sout. Furthermore, the control circuit 602 can narrow down the range including the value of the analog signal Sin to the range designated by an arrow 702.

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Therefore, in the subsequent successive-approximation, the control circuit 602 determines the lower bits of the digital signal Sout by performing the binary search using the capacitors cp0 to cp4.

As described above, also the AD converter 600, in a similar manner with the AD converter 100, can reduce the circuit scale for performing the successive-approximation, along with reducing the time required for the AD-conversion. Also, in a similar manner with the AD converter 300, the AD converter 600 may determine the value of the digital signal Sout by the successive-approximation after expanding the range narrowed down by the ramp comparison by adding the capacitor cpa and the switch swa. Accordingly, even in a case where the comparator CMP misjudges in the comparison between the value of the ramp signal V_{mp} and the value of the analog signal Sin, the misjudgment is corrected in the subsequent successive-approximation.

Similar to the AD converters 100 or 300, The AD converter 600 can also be applied to a solid-state imaging device. In a case where the AD converter 600 performs AD-conversion on the reference signal, the control circuit 602 may skip the ramp comparison, and may perform only the successive-approximation. In particular, without performing the ramp comparison, the control circuit 602 may determine that the analog signal Sin is included in the minimum range narrowed down by the successive-approximation, that is, at least 0 and less than $V_{ref}/16$. And, it may perform the successive-approximation in this range. The control circuit 602 then decides the digital value after the completion of the successive-approximation, assuming that the upper bits decided by the ramp comparison are all 0s. Accordingly, the time required for the successive-approximation can be reduced. Also, the AD converter 600 may perform part of the ramp comparison. For example, the monotonous decrease of the comparison signal V_{cmp} may start from $V_{ref}/4$, and upper bits may be decided by the ramp comparison. In this case, the upper two bits of the digital value are assumed in advance to be 0.

Next, referring to FIG. 9, an exemplary circuit configuration of a reference voltage generation circuit 807 and a ramp signal generation circuit 808 will be described. As shown in FIG. 9, the ramp signal generation circuit 808 has a plurality of p-channel transistors pt0 to ptn having binary weighted drivabilities. Gates of the p-channel transistors pt0 to ptn are applied with a predetermined voltage BIAS from a bias block. The p-channel transistors pt0 to ptn are connected to a resistance element rt1 through respective switches sb0 to sbn. A current value flowing through the resistance element rt1 varies depending on the combination of switches sb0 to sbn that are made conductive. The current value is converted by the resistance element rt1 to a voltage, and this voltage is output as the ramp signal V_{mp}. A ramp signal V_{mp} which changes in time by a predetermined amount is generated by turning on and off the switches sb0 to sbn by a counter cnt.

The reference voltage generation circuit 807 has a p-channel transistor ptr and a resistance element rt2. The voltage BIAS is also applied to the p-channel transistor ptr, and the current flowing through the p-channel transistor ptr is converted to a voltage by the resistance element rt2, and this voltage is supplied to an operational amplifier OP. The operational amplifier OP acts as a voltage follower, and outputs the reference voltage V_{ref}. By adjusting the weight of p-channel transistor ptr, a change amount (amplitude) of the ramp signal V_{mp} can be made equal to the value of the reference voltage V_{ref}.

While the present invention has been described with reference to exemplary embodiments, it is to be understood that the invention is not limited to the disclosed exemplary

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embodiments. The scope of the following claims is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures and functions.

This application claims the benefit of Japanese Patent Application No. 2012-141462, filed Jun. 22, 2012, which is hereby incorporated by reference herein in its entirety.

What is claimed is:

1. A solid-state imaging device comprising an AD converter, and a plurality of pixels configured to supply an analog signal to the AD converter,

wherein the AD converter comprises:

a generation circuit including a plurality of capacitors having binary weighted capacitance values and a switch circuit configured to select at least one of the capacitors from the plurality of capacitors, the generation circuit being configured to generate a comparison signal according to a composite capacitance value of the at least one of the capacitors selected by the switch circuit;

a comparator circuit configured to compare the analog signal and the comparison signal;

a control circuit configured to perform a first comparison operation to narrow down a range including a value of the analog signal by performing a binary search, in which a value of the comparison signal is changed by changing the composite capacitance value based on a comparison result of the comparator circuit, and to perform a second comparison operation to narrow down a range including the value of the analog signal based on a comparison result of the comparator circuit during a period when the comparison signal is changed at a constant rate,

wherein the plurality of pixels supply, to the AD converter, a reference signal corresponding to a reset level of the pixel and an image signal having image information as the analog signals,

wherein the AD converter converts the reference signal and the image signal in different ways such that

when the image signal is supplied, the AD converter converts the image signal to a first digital signal by performing a first selected operation selected from the first comparison operation and the second comparison operation and then performing a second selected operation selected from the first comparison operation and the second comparison operation in the range narrowed down by the first operation, the second selected operation being different from the first selected operation, and

when the reference signal is supplied, the AD converter converts the reference signal to a second digital signal by performing the second selected operation without performing the first selected operation.

2. The device according to claim 1, wherein the AD converter starts the second selected operation from a range that is wider than the range which is narrowed down by the first selected operation.

3. The device according to claim 2, wherein the AD converter starts the second selected operation from a range having a width not more than double the range narrowed down by the first selected operation.

4. The device according to claim 1, wherein the first operation is the first selected comparison operation and the second selected operation is the second comparison operation.

5. The device according to claim 1, wherein the first selected operation is the second comparison operation and the second selected operation is the first comparison operation.

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6. The device according to claim 1, wherein the generation circuit generates the comparison signal by converting a reference voltage with the composite capacitance value, and changes the comparison signal by adding a ramp signal to the comparison signal, and an amount of variance of the ramp signal, during the second comparison operation, is equal to the reference voltage.

7. A solid-state imaging device comprising an AD converter, and a plurality of pixels configured to supply an analog signal to the AD converter,

wherein the AD converter comprises:

a generation circuit including a plurality of capacitors having binary weighted capacitance values, and a switch circuit configured to select at least one of the capacitors from the plurality of capacitors, the generation circuit being configured to generate a comparison signal according to a composite capacitance value of the at least one of the capacitors selected by the switch circuit;

a comparator circuit configured to compare the analog signal and the comparison signal;

a control circuit configured to perform a first comparison operation of comparing the comparison signal with the analog signal while causing the switch circuit to change combination of the at least one of the capacitors based on a comparison result of the comparator circuit, and to perform a second comparison operation of comparing the comparison signal with the analog signal while changing the comparison signal based on a ramp signal input to the generation circuit

wherein the plurality of pixels supply, to the AD converter, a reference signal corresponding to a reset level of the pixel, and an image signal having image information as the analog signals,

wherein the AD converter converts the reference signal and the image signal in different ways such that

when the image signal is supplied, the AD converter converts the image signal to a first digital signal by performing a first selected operation selected from the first comparison operation and the second comparison operation and then performing a second selected operation selected from the first comparison operation and the second comparison operation in the range narrowed down by the first operation, the second selected operation being different from the first selected operation, and

when the reference signal is supplied, the AD converter converts the reference signal to a second digital signal by performing the second selected operation without performing the first selected operation.

8. The device according to claim 7, wherein the AD converter starts the second selected operation from a range that is wider than the range which is narrowed down by the first selected operation.

9. The device according to claim 8, wherein the AD converter starts the second selected operation from a range having a width not more than double the range narrowed down by the first selected operation.

10. The device according to claim 7, wherein the first selected operation is the first comparison operation and the second selected operation is the second comparison operation.

11. The device according to claim 7, wherein the first selected operation is the second comparison operation and the second selected operation is the first comparison operation.

12. The device according to claim 7, wherein the generation circuit generates the comparison signal by converting a

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reference voltage with the composite capacitance value, and changes the comparison signal by adding the ramp signal to the comparison signal, and

an amount of variance of the ramp signal, during the second comparison operation, is equal to the reference voltage. 5

13. The device according to claim 7, wherein the generation circuit includes a capacitor configured to receive the ramp signal.

14. The device according to claim 13, wherein a capacitance value of the capacitor configured to receive the ramp 10 signal is equal to one of the binary weighted capacitance values.

15. The device according to claim 13, wherein a capacitance value of the capacitor configured to receive the ramp 15 signal is different from any one of the binary weighted capacitance values.

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